SURVEYING FOR ARCHÆOLOGISTS.[1]

VI.—THE FINDING OF DATES.

(1) *By Solstitial Alignments.*

IN the astronomical study of ancient monuments, the archæologist's measures of azimuth and altitude enable him to determine the declination of the celestial bodies the rising and setting places of which are indicated by the direction of avenues or of outstanding stones seen from the centre of a circle.

But this, after all, is but the means to an end; it is only a first step.

The second step is to find, *if possible,* from the declinations, the time at which the sun or a star occupied these declinations. This tells us when the "ancient" stone monument was set out, and because the monument is an ancient one it is certain that the declination of the sun at a solstice and that of the stars were different from what they are now. I will deal with the sun first.

In consequence of causes which need not be gone into here, the angle between the plane of the earth's equator and of the ecliptic—called the obliquity of the ecliptic—is getting smaller. The result is that the sun's declination at a solstice, which defines the value of the obliquity, is less now than it was in times past.

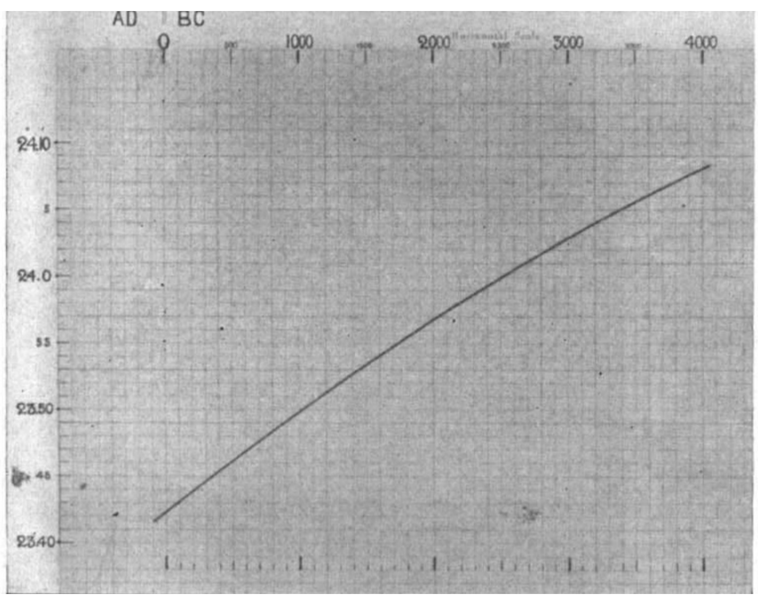

FIG. 25.—Variation of the Obliquity of the Ecliptic, 100 A.D.–4000 B.C. (Stockwell's Values.)

This rate of change is very slow, as will be gathered from the diagram—Fig. 25—a little more than half a degree in 4000 years. The present value is 23° 27′; in 1680 B.C., the date of the erection of the sarsens at Stonehenge, according to the measures made by Mr. Penrose and myself, it was 23° 55′.

Now in these latitudes this change of half a degree in declination produces a greater change in the azimuth. In a previous diagram I have given not only the solstitial azimuth at the present day, in lat. 50° N., but also that of 1680 B.C., showing that there is a difference of nearly one degree; still, this is not certain of detection considering monument conditions.

Hence, in attempting to deduce a definite date from a solstitial alignment, favourable conditions of the monument, such as the avenue at Stonehenge, and exceedingly careful observations are absolutely essential. Any others are practically valueless, because, as will be gathered from the curve, Fig. 25, an error of only 10′ in the derived declination produces an error of some 1300 years in the date.

It is only the solstitial alignment that can help us, in consequence of the sun then arriving at the extreme declination. An equinoctial alignment is of no use, because with any value of the obliquity the sun's declination at the equinox is always 0°.

From May–November alignments it is impossible to derive any date, owing to the rapidity with which the sun's declination changes at those seasons of the year—more than a quarter of a degree each day.

The only serious attempt so far to derive a date by an alignment to the solstice, using the change in the obliquity of the ecliptic, was made by Mr. Penrose and myself at Stonehenge, but there is little doubt that as our knowledge of the monuments increases other alignments as definite as the avenue at Stonehenge will be found.

The conditions of observation at Stonehenge will be gathered from Fig. 26, in which the line drawn through the centres of the naos, circle and vallum, and passing to the north of the Friar's Heel, represents the common direction of the avenue and of the axis of the temple.

(2) *By Stellar Alignments.*

In previous notes I showed how with certain data, including a measured azimuth and altitude, the declination of the star which rose on the alignment indicated by the monument could be found. Having this declination, the next step is to inquire which star occupied that position in times past, and *when.*

In dealing with stars, the problem of finding a date is much more within the possibility of observation than in the case of the sun. The stars change their declination 47° in 25,800 years, that is, 1° in 550 years on the average, and some stars at some times change it much more rapidly.

This relatively very great change in the declination of stars from century to century is brought about by the action of the sun and moon.

The action referred to does not depend upon the actual attractions of the sun and moon upon the earth as a whole, which are in the proportion of 120 to 1, but upon the difference of the attraction of each upon the earth's bulge at the equator, arising from the fact that the equatorial diameter is the larger. As the sun's distance is so great compared with the diameter of the earth, the differential effect of the sun's action is small; but, as the moon is so near, it is so considerable that her precessional action is three times that of the sun.

An important result of the action on the protuberance has now to be considered. The change in the position of the equator caused by the attraction is brought about by a rolling motion, which is necessarily accompanied by a change in the earth's axis.

In Fig. 27, *ab* represents the plane of the ecliptic, CQ a line perpendicular to it, *hfe* the position of the equator at any time at which it intersects the plane of the ecliptic in *e*. The position of the earth's axis is in the direction C*p*. When, by virtue of the precessional movement, the equator has taken up the

[1] Continued from vol. lxxviii., p. 574.

position *lkg*, crossing the plane of the ecliptic in *g*, the earth's axis will occupy the position C*p*′.

The lines C*p* and C*p*′ have both the same inclination to CQ. It follows, therefore, that the motion of the earth's axis due to precession consists in a slow revolution round the axis of the celestial sphere, perpendicular to the plane of the ecliptic. During this movement, while the inclination of the two planes remains nearly $23\frac{1}{2}°$, the position of the celestial pole, and consequently our pole star, are constantly changing.

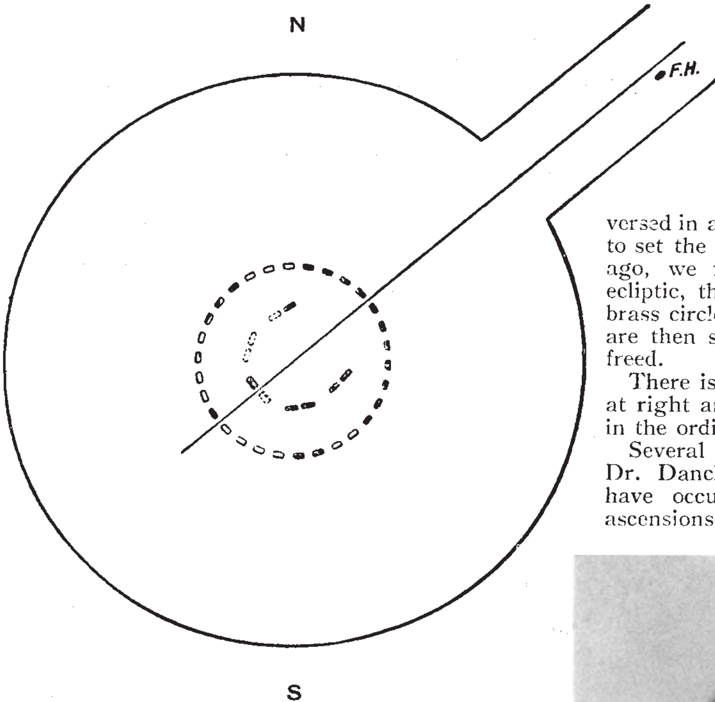

FIG. 26.—General Plan of Stonehenge; the outer circle, naos and avenue; F.H. = Friar's Heel.

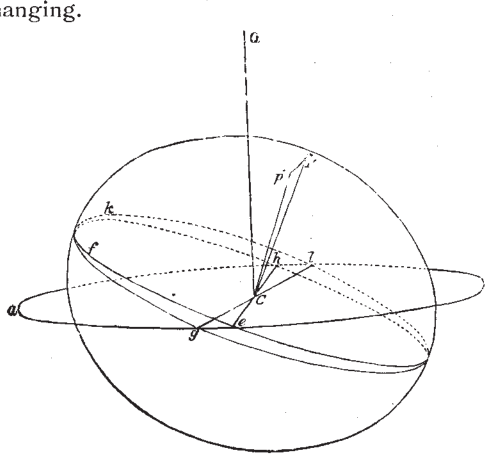

FIG. 27.—Showing the effects of precession on the position of the earth's axis.

An ordinary celestial globe represents the right ascensions and declinations of stars at some epoch near our own time, but some years ago I devised a globe in which the changes brought about by this precessional movement can be shown in a very concrete manner, so that the changes in position can be readily understood.

The precessional globe, as I called it, is, in fact, arranged so that the position of the celestial pole and equator, and consequently the positions of the stars, may be represented at any epoch. In the globe pivots are provided so that it may be turned on the pole of the ecliptic; round these at a radius of $23\frac{1}{2}°$ are brass circles (one of which is shown), with holes in them, each of which may also be used as a pivot. One pair of pivots on the latter circles corresponds to the present celestial poles, and represents the heavens as they are at the present time; the globe is arranged to turn on these, the ecliptic pivots being thrown out of gear. Other pivots on the brass circles correspond to other dates, the whole circle being traversed in about 25,800 years. For example, if we wish to set the globe to represent the conditions 2000 years ago, we first swing the globe on the poles of the ecliptic, then turn it until the desired points on the brass circle are brought under the other pivots. These are then screwed into position, and the first two are freed.

There is a brass meridian, passing round the globe at right angles to the horizon, which is graduated as in the ordinary celestial globe.

Several astronomers, including the late Mr. Hind, Dr. Danckworth, Dr. Lockyer, and Mr. Stockwell, have occupied themselves in calculating the right ascensions and declinations occupied by stars in past times. Curves given in "Stonehenge" (pp. 116–117) show the changing declination of the brightest stars—and this is the component of greatest importance to the archæologist—from 250 A.D. to 2150 B.C.

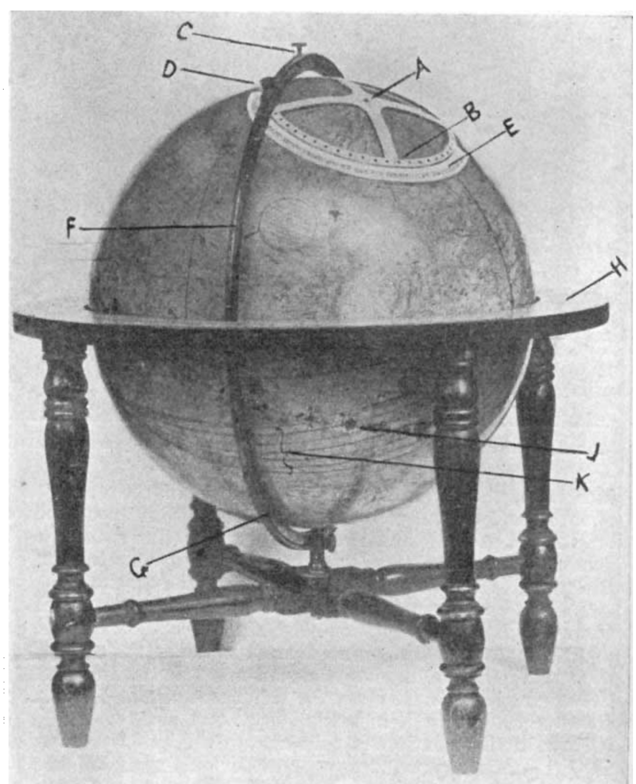

FIG. 28.—The Precessional Globe. A, Pole of ecliptic; B, brass circle, with holes on positions of celestial poles at different epochs; C, screw pivot for N. pole of ecliptic; D, screw pivot for N. celestial pole at different epochs; E, scale of years denoting position of celestial pole at definite epochs (set for 1364 B.C.); F–G, brass meridian; H, H, H, H, wooden horizon; J, ecliptic; K, celestial equators drawn for different epochs.

A glance at the curves will show that the same declination is occupied by different stars at different dates; hence it may happen that the declination found fits more than one star within probable date limits, and so we have to decide which is the more likely star to have been observed. It might at first sight seem that it would be difficult to settle which star is really in question. But in practice the difficulty does not often arise. We now know that the stars used were those in high northern or southern declinations for noting the time at night in the way the Egyptian temples have familiarised us with, and stars nearer the equator to serve as "morning stars," warners of sunrise.

The stars with about the dates already revealed by the work of the last few years may certainly be considered in the first instance.

It is really not a remarkable fact that so few stars are in question, for the use made of them was very definite. Capella, Arcturus, α Capricorni, Pleiades, and Antares almost exhaust the list.

The use of the precessional globe saves many intricate and laborious calculations when only an approximation is required. Thus warning stars at any quarter of the May or solstitial year at any given date may be found by rectifying the globe for the latitude of the place of observation, marking the equator at that date by a circle of water-colour paint by holding a camel's-hair pencil at the east point of the wooden horizon, and rotating the globe. The intersection of the equator and the ecliptic gives us the equinoxes at that date, their greatest separation the solstices. With these data we can mark the required position of the sun on the ecliptic.

This done, if we rotate the globe so as to bring the sun's place 10° below the upper surface of the wooden horizon, the star the rising of which can be used as a warner will be seen on the horizon.

Nor does the use of the globe end here. With a given azimuth, which are all marked on the wooden horizon, the globe may be adjusted to different dates and then rotated until at a certain date a star rises at that azimuth.

NORMAN LOCKYER.

GEODETIC SURVEYS.

THE latest volume (vol. xviii.) of the Great Trigonometrical Survey of India contains the records of astronomical observations for latitude extending over the last twenty years. It is, in effect, the continuation of vol. xi., and brings this particular department of Indian Survey statistics up to date. It consists chiefly of tabulated records; 543 pages alone in part ii. being absorbed by tables of astronomical latitudes. There is therefore nothing to offer in the way of remark or criticism on the great bulk of detail contained in this volume except congratulation on the completion of a work involving so much labour in compilation. It is, perhaps, the most interesting of the whole series of Great Trigonometrical Survey records and the interest of it to the general reader lies in the preface, where Colonel Burrard, in plain and simple language, gives the reasons for the faith that is in him as regards the present position of geodetic work in India.

To those who have pinned their faith to the rigid accuracy of geodetic triangulation as the basis of fixed points for the further extension of minor systems of triangulation and of topographical survey, it may at first sight appear somewhat disturbing to be assured that there is no finality in sight for the value of any fixed point in India, either in latitude, longitude or altitude. Geodetic science can only develop on a system of trial and error. Only by the most rigidly exact systems of measurement possible to human agency can the shape of the earth's figure be precisely determined, and only, when the precise shape of that figure has been determined, can geodetic calculations be satisfactorily computed. Hitherto these calculations in India have been based on an assumed earth-figure known as Everest's spheroid, and although this assumption is not absolutely justified by continuous observation, Col. Burrard rightly maintains that it would be a mistake to break the continuity (and thereby destroy much of the value) of the Great Trigonometrical Survey series by the introduction of tables based on new, and possibly only half-digested, data. Similarly he pleads for absolute accuracy in the determination of latitudes, for it is only when the riddle of the earth's shape shall be solved by the men of science of the future, and the pathway to positive deductions therefrom straightened out, that the full value of this most remarkable body of results (obtained by new and more perfect instruments from observations of stars of which the position is now more certainly known than heretofore) can be effectively utilised

The deflection of the plumb-line forms one of the principal subjects of scientific investigation of which the record is to be found in this book. This deflection is determined by the difference in latitude obtained for any fixed point between the results of geodetic triangulation and of astronomical observation. For reasons already suggested in connection with the assumption of the earth's figure, as well as the fact that the origin of geodetic latitudes in India (at the Kalianpur base) is itself an assumption, there still remains an element of uncertainty in these determinations. They are exceedingly interesting. "In the Himalayas" (which is, perhaps, a slightly vague definition) the deflection amounts to −35·29s.; at the foot of the Himalayas it is −10·90s.; in central India it amounts to +0·94s. But it must be remembered that in dealing with this matter of rigid accuracy we have still to reckon with minutely small errors, quantities that are immaterial for the practical purpose of supplying a basis for map-making. For instance, the most improved methods of observing with the best of new instruments only displaces the assumed value of the Kalianpur latitude by 0·3″. In the matter of longitude there is, however, a recognised error of 2′ 27″, which is an error too large to be neglected. This has to be eliminated from Indian mapping; although, again, Col. Burrard deprecates any interference with the continuity of Great Trigonometrical Survey records in the series ended by this eighteenth volume. To this extent Indian topography and Indian geodesy must remain discrepant for a space of time.

There is, however, one element of disruption in Indian Geodetic Survey work with which no man of science can deal. This is caused by earthquakes, and the resulting displacement of mark-stones is not easily determined. There may be little relative displacement over a large area, whilst the absolute displacement of the whole area may be considerable. It is impossible to re-triangulate the vast spaces which would be necessary to determine this, nor does it appear to be at all easy to discover what may be the effect of such disturbances in altitude. The most careful levelling (three times repeated) over the eighteen miles separating Dehra from Mussoorie only revealed a probable diminution of 5½ inches in the Himalayan altitudes at Mussoorie after the latest, and most violent, earthquake. Meanwhile geodetic science fulfils its mission admirably in the great practical work of establishing the basis for topographical surveys. These never can be affected by those small geodetic adjustments which are all-important to the scientific theorist, although it